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ABSTRACT

This paper reports on the concentrations of radon found within a sample of 378 elementary schools in California. Long-term alpha-track radon detectors were placed in 6,485 classrooms within participating schools to detect radon levels for between 220 to 366 days. Only classrooms were tested. Results show that about 5.6 percent of the schools tested had at least one classroom with more than the maximum level of radon (4pCi/l) as recommended by the U.S. Environmental Protection Agency; the maximum measured classroom radon level was 12.8 pCi/l. Affected schools had from one to six classrooms exceeding the level. An adjusted analysis suggests statewide rates of excessive radon to be in 4.7 percent of the schools. Recommendations and statistical data conclude the report. (Contains 12 references.) (GR)

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SURVEY OF INDOOR RADON CONCENTRATIONS IN CALIFORNIA ELEMENTARY SCHOOLS

Final Report
May 1998

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EXECUTIVE SUMMARY

A study was conducted to determine the annual average radon concentrations in academic classrooms of selected public elementary schools in California. The objectives were to estimate proportions and number of schools and classrooms with radon concentrations exceeding the U.S. Environmental Protection Agency (EPA) recommended indoor radon limit of 4 picocuries per liter (pCi/l) for the entire state and for different geographic regions. The California Department of Health Services (CDHS) Radon Program designed the survey and collected the data in 1991-92; the CDHS Indoor Air Quality Section conducted data analyses included in this report.

The postal zip code zones of the state were grouped into three geographic regions representing high, moderate and low radon potentials. This classification by a geologist from California Division of Mines and Geology (DMG) was based mainly on the bedrock geology uranium potential and the U.S. Geological Survey Equivalent Uranium Map. Letters requesting participation in the study were sent to all elementary school districts in the state. From the 1123 schools willing to participate, 378 schools were selected; all schools in the high (50) and medium (65) radon potential regions were included due to limited schools in the regions. Long term alpha-track radon detectors with detailed instructions for placement were sent to the selected schools. A total of 6485 classrooms were monitored for annual radon concentrations during the 1991-1992 school year.

In the statewide survey, 5.6% of schools (21/378) had at least one classroom with more than 4 pCi/l, the current U.S. EPA action level. In Santa Barbara county, 16% (4/25) had at least one classrooms above this level. Affected schools had an average of two classrooms, with a range of one to six classrooms exceeding the level. The maximum measured classroom radon level was 12.8 pCi/l. Because the sample of schools was weighted towards geological areas with a greater probability of radon exposure, an adjusted analysis suggests a statewide rate of 4.7% schools. Statistical analysis indicates that there is no significant difference in geometric means of average school radon measurements between low and medium radon potential regions, so that the two are lumped as "low" regions. Although there was about a three-fold increased likelihood of finding schools with at least one classroom exceeding the EPA level in high radon potential regions, the "low" radon potential regions contained the majority of schools and the majority of schools with one or more classrooms exceeding the EPA level. Thus, the zip code classification is not sensitive nor specific screening approach.

The CDHS is attempting to develop better methods for a school screening program. Without selective screening, to make measurements in every classroom of every schools in the state would cost approximately $0.9 to 1.25 million. There is limited information about the cost and efficacy of classroom interventions for radon. A preliminary estimate for the total mitigation cost statewide is approximately $250,000-500,000. Hence, the total estimated costs of screening and mitigation are between $1.15 to 1.75 million. If secondary schools are included, the estimates would increase proportionally.

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INTRODUCTION

Radon is a radioactive gas resulting from the decay of uranium, an element present in nearly all soils. Radon, which is colorless and odorless, contaminates indoor air by diffusing from soils and rocks, and by infiltrating housing foundations.

Causal association between exposure to radon and lung cancer has been demonstrated in epidemiological studies around the world. The U.S. Environmental Protection Agency (EPA) estimated that approximately 14,000 lung cancer deaths in the United States per year are due to residential radon exposures, with an uncertainty range of 7,000 to 30,000. (EPA, 1993). The EPA has recommended that residences with annual average radon concentrations exceeding 4 pCi/l be modified within a reasonable time to reduce the risk of lung cancer.

The objective of this study was to determine the distribution and levels of radon gas in elementary classrooms of public schools in California. The California Radon Program of the Department of Health Services (DHS) designed the survey and collected the data in 1991-92; the DHS Indoor Air Program conducted data analyses included in this report. The survey consisted of placement and exposure of alpha track detectors (ATD) device in 6485 public elementary classrooms for a complete school year (September 1991 to June 1992). The survey was limited to elementary schools because these represent the greatest number of schools within the public school system, which consists of elementary, junior and high schools, and therefore provided the best geographic distribution. In addition, elementary schools constitute the longest one-site exposure potential of radon for students.

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STUDY METHODS

Selection of Participating Schools

Elementary school districts were identified from a database compiled by the Department of General Services, Office of Local Assistance. Virtually all California schools were included in the database. A letter requesting participation of the survey was sent to each district superintendent. Among 966 elementary school districts contacted, 314 districts responded (32.5%), and 242 districts with 1123 schools were willing to participate. There are total of 5362 elementary schools in California (QED State School Guide, 1997-1998).

To select a sample from the 1123 schools for the survey, the postal zip code zones of the schools were graded into three geographic regions representing high, moderate and low radon potentials. The classification, which was developed with staff of the State Division of Mines and Geology (DMG), was based on the following:

1) Bedrock geology uranium potential (the potential of a given rock unit to have higher uranium content than average for the earth's crust);

2) Known locations of uranium mineralization;

3) U.S. Geological Survey Equivalent Uranium Map (USGS-EUM)

4) California Statewide Radon Survey of Homes by the Department of Health Services (Liu et al., 1990)

A scoring system was used to rank the zip code areas. One point was given to a zip code area if it contained favorable source rocks for radon, and one point was given if the area was 3 ppm (parts per million) or higher equivalent uranium on the USGS-EUM. Areas with scores of 2 were then labeled high, scores of 1 were labeled medium, and scores of 0 were labeled low. These classifications were slightly adjusted using additional information from the Statewide Radon Survey of homes, and knowledge of locations of uranium mineral deposits in the state. The three levels of radon potential zones were used to identify school sites for radon testing.

All schools in the high and medium radon potential codes that volunteered to participate were included due to limited schools in the regions. A total of 50 schools with 915 classrooms were in high radon potential zip code areas, and 65 schools with 1199 classrooms in medium radon potential areas; 263 schools with 4371 classrooms were randomly selected from remaining participating schools in low radon potential areas. In total, 378 schools with 6485 classrooms were selected for the survey.

Measurement

Long term alpha-track radon detectors (ATD) were mailed to the selected schools with detailed instructions for placement. Detectors, one in every classroom, were exposed from 220 to 366 days with an average of 272 days. All academic classrooms in fixed buildings were tested. Classrooms in portable structures in approximately 50% of the participating schools were tested. Administrative areas, gymnasiums, auditoriums, cafeterias or lounges were not tested.

Measurements were made under the normal operating conditions of the school classrooms. The ATDs were placed where detectors would not be disturbed during the measurement period, away from drafts caused by HVAC vents, windows, and doors or locations near excessive heat such as in direct sunlight, high humidity. The detectors were placed at least 75 cm above the floor and at least 10 cm from any objects. For each ATD, a log sheet was used to record the following information: 1) school identifier; 2) start/stop dates; 3) exact location of detector and the unique identifier of the classroom; 4) serial number of the detector and; 5) any other information that may be useful for data interpretation.

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RESULTS

Location Distribution of High Radon Potential Schools

Locations of elementary schools selected to participate in the radon survey are shown in Figure 1. Figures

2 and 3 show the locations of selected schools with at least one measured classroom radon level exceeding 4 pCi/L (21 schools) and 2 pCi/L (67 schools) respectively.

Schools with at Least One Classroom Exceeding 4 pCi/L

A total of 21 schools (5.6 %) had one or more rooms at or above 4 pCi/L. In Santa Barbara county, 4 of the 25 schools or 16% had one or more classrooms above this level. There are 14 schools (14/263=5.3%) at or above 4 pCi/l in low radon potential zones, 0 (0/65=0%) in medium zones, and 7 (7/50=14%) in high zones. When low and medium zones are lumped, the rate for low/medium zones is 4.27% (14/328).

Relative risk (RR) of finding "problem schools" in high radon potential zones compared to low/medium potential zones is RR=14%/4.27%=3.28. This RR with confidence interval (1.43, 7.53) is significant at the 0.05 level, since the interval does not include 1. Thus, schools in the high zones are 3.28 times as likely to have radon at or above 4 pCi/l in one or more classrooms than schools in the low/medium zones.

Histograms of affected classrooms in the problem schools are shown in Figure 4. The maximum number of affected classrooms at a single school was 6 out of 23 classrooms. One school had 4 out of 5 classrooms above the recommended EPA level. The average number of affected classrooms at this level per school was 2 (42 classrooms/21 schools). The maximum measured classroom radon level was 12.8 pCi/L.

Distributions of Average School and Classroom Radon Measurement

The distribution of indoor radon concentrations is approximately lognormal (Nero et. al. 1990). A histogram of annual average school radon measurements is shown in Figure 5 and corresponds well to a lognormal distribution with a geometric mean (GM) of 0.46 and a geometric standard deviation (GSD) of 2.07 (Table 1). The average school radon measurement is a mean of all classroom measurements in the school. In addition, a histogram of annual average classroom radon measurements is shown in Figure 6 with a geometric mean (GM) of 0.33 and a geometric standard deviation (GSD) of 2.96 (Table 2).

Statistical Test for Radon Potential Classification

A t-test, as summarized in Table 1, indicated that there was no significant difference in GM of average school radon measurements between low and medium radon potential zones (P=0.112). Significant differences in GMs were found between the low and high radon potential zones (P=0.007), and between the medium and high zones (P=0.002). Because of the results of the significant test, the data from low and medium zones are combined. The combined distribution of the classroom radon measurements has a GM of 0.31 and a GSD of 2.95, compared with the classroom radon distribution of high radon potential zones which has a GM of 0.54 and a GSD of 2.56, as shown in Table 2.

Measured Proportion of Classrooms Exceeding 4 pCi/L

According to classroom radon statistical distributions above, the measured proportion of California elementary school classrooms exceeding 4 pCi/l is 1.1%, according to a lognormal distribution. The measured proportions of classrooms exceeding 4 pCi/l in low/medium, and high radon potential zones were 0.9 and 2% respectively (Table 3).

Comparison of Radon Levels Between Residence and Classroom

Table 4 compares radon level between the elementary classroom and residence of the State. The residence survey was conducted two years earlier than the school survey (Liu et al., 1990,1991). The classroom distribution has a lower GM, higher GSD and larger percentage of rooms exceeding 4 pCi/L.

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DISCUSSION

School site visits were made to 10 selected schools, and telephone interviews were conducted with school personnel at four other schools. All of the site visits and three of the four phone interviews were to schools having one or more classrooms measuring 4 pCi/L or greater. The three schools with the highest classroom radon levels measured during this study (12.8, 12.3, and 10.3 pCi/L) were visited. A visit was made to one school that had no radon problem classrooms, but was near a school with radon problems, and information was obtained for comparison purposes. These site visits and interviews provided information for assessing the relative importance of some of the controlling factors for indoor radon levels in schools. These factors are: the natural setting (geology, soil type, and climate), structural setting (building design, foundation type, type of heating and air conditioning system, and ventilation) and human behaviors (teacher habits related to indoor classroom conditions, such as windows and doors usually open or closed, room temperature setting etc.). The details of the site visits and interviews are summarized elsewhere (Churchill, 1993).

Standard adjustment of the problem school rate is necessary, because the samples in the school survey were not randomly selected. If all schools (1123) that agreed to participate the survey are assumed to be randomly distributed throughout the State, the "true" proportions of schools in the high, medium and low radon potential zones are 4.5% (50/1123), 5.8% (65/1123) and 89.7% (1008/1123) respectively. The samples (378 schools) for radon measurements included all schools in the high and medium radon potential zones (50 and 65 schools respectively), and a subset of schools in the low radon potential zone (263). The "sample" proportions of schools in the high, medium and low radon potential zones are 13.2% (50/378), 17.2% (65/378) and 69.6% (263/378) respectively. Hence, the survey was over represented by schools in the high and medium radon potential zones. The overall sample statistics if presented in an unweighted fashion would tend to overestimate the radon potential in schools. So the overall percent of schools in the state with at least one classroom exceeding 4 pCi/l would be less than 5.6% calculated above. The adjusted analysis suggests a rate around 4.71% statewide (1). However, this overestimation was small for the average radon measurement of GMs in Table 1. The adjusted GM for the entire State is 0.458 pCi/L (2) compared with the unadjusted GM of 0.460 pCi/L.

Classification of the three radon potential zones was crude, and actual measurements supported two potential radon zone, high and low, classification. The classification was based mainly on information of uranium potential. There is no strict correlation between radon concentration and uranium concentration in soil (Cothern, 1987). In fact, good correlation exist for only the two extremes: if the uranium concentration is very low or very high in the source material (rock or sediments), then the radon concentration is likely to be very low or very high respectively, in the adjacent soil gas. However, if the uranium concentration is not very low or very high, the radon concentrations can range widely. Other factors are then dominant in controlling radon concentrations.

An enhanced classification (Churchill and Youngs, 1993) was done by incorporating other information on geological setting, and soil type etc. The three parameters that best predict the potential for excessive indoor radon at school sites are: 1) the presence of uranium source rocks; 2) soil hydrological group; and 3) the average weighted soil permeability range.

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CONCLUSION AND RECOMMENDATIONS

1) About 5.6% of schools (21) in this survey of 378 schools had at least one classroom with more than 4 pCi/l, the level that U.S. EPA uses to recommend mitigation. In Santa Barbara county, four of the 25

schools or 16% had one or more classrooms above this level. Since Santa Barbara has a total of 67 elementary schools (QED State School Guide, 1997& 1998), one could expect about 11 of these schools to have one or more classrooms above this level.

2) The sample of schools was weighted towards geological areas with a greater probability of radon exposure, such as Santa Barbara county. Hence, the overall percent in the state would be expected to be less than the 5.6% mentioned above. Adjusted analysis suggests a rate of 4.7% statewide. Since there are 5362 elementary schools in the state, that comes to about 252 schools.

3) Among the 21 schools with one or more classrooms above 4 pCi/l, the maximum number of affected classrooms measured at a single school was six. Our preliminary analysis suggests that the average number of affected classrooms per school was two, although the average number of classrooms per school was higher in Santa Barbara and Ventura counties.

4) Using geological classifications to predict the schools with high radon is not as helpful as one might hope. According to the original study design, each school that agreed to participate was classified into high, medium and low likelihood to have high radon. In our subsequent analyses, we found that medium and low groups were statistically indistinguishable. Yet, even though the high risk group was more likely to have high radon, a greater total number of high radon schools were found in the 95.5% of schools in "high radon unlikely" zip codes (i.e., low and medium groups). Put another way, if we looked at only the schools that the geologists might predict as "high risk", we would miss the majority affected classrooms.

Follow-up to Survey

The 21 schools with classroom radon measured above the EPA radon level were notified by DHS in 1992. School officials were provided the EPA recommendations for radon mitigation. However, it is not known what, if any, actions were taken at these schools. Since 1992, EPA has published several advisories on radon mitigation for schools (EPA, 1994). It would be worthwhile for EPA to fund a follow-up investigation of these 21 schools to learn more about the effectiveness of school mitigation, the long-term stability of annual radon measurements, and the factors that influence schools officials' decisions to mitigate or not.

Screening and Mitigation

From the above data, we attempted to calculate the likely cost of radon mitigation for California elementary schools. There is limited information about the cost and efficacy of classroom interventions for radon. An EPA study (1989) indicates that radon mitigation and diagnostic techniques developed for residential houses can be applied successfully in schools. Leovic and Craig (1994) estimate that the average total cost of conducting diagnostics and installing an active soil depressurization (ASD) system in an existing school building is about $0.50/ft2. If the cost of $500-1000 is applied to each classroom, the average mitigation cost per affected school would thus be between $1000-2000 (two classrooms). Statewide, the total cost would come to approximately $250,000-500,000. This estimate should be revised with more current data on the costs of radon mitigation for schools, but it does provide the likely magnitude.

One approach to school radon screening is to measure radon in every classroom of every school. Assuming an average of 15 classrooms per school and $10-15 per test, measurements would cost only $150-200 per school. Excluding the cost of staff to administer this program, the total would be approximately $0.9 to 1.25 million statewide. Hence, the total costs of screen and mitigation are between $1.15 to 1.75 million. If secondary schools are included, the estimates would increase proportionally.

With this universal elementary school screening approach, the total number of lung cancer cases avoided is 7.4 (3). Therefore, the cost per cancer avoided by this approach would be $153,000~233,000.

We feel that it should be possible to develop a better screening tool to lower the total number of classrooms to be tested. The available data indicate that relocatable classrooms, for example, do not need to be tested for radon. In addition, short-term screening may be used to select classrooms for long-term measurements. We are working on refining screening methods based on statistical modeling approaches now with additional data and more refined geology maps. The radon potential classification model developed by DMG (Churchill, 1993), based mainly on univariate analysis, and should be improved using multivariate statistical methods. The model should be further improved by incorporating the non-geological factors such as building structure and type, human factors as suggested by Liu et. al. (1990). Furthermore, the large spatial variability of indoor radon concentrations in individual buildings indicates the need for development of higher resolution, site-specific radon potential maps, which were developed preliminarily by DMG (Churchill, 1995) for two counties in California. The site-specific radon potential maps can help building code officials to decide zones that require radon resistant building practices. On the other hand, a population radon risk map that considers population density distribution and exposure information could be developed to assist various government agencies and organizations to target their radon programs and resources to areas of the highest risk. Finally, a geographic information system (GIS) could be applied to integrate the diverse sources of radon-relevant information currently available and to assist in understanding radon issues and managing indoor radon problems in California.

At the same time, it seems to us that the next step is to focus on providing information on effective methods for lowering radon in classrooms where levels are now high. We are currently reviewing literature on such methods, studies to evaluate how effective they are in practice, and how much they cost. Funds are needed for supporting these activities. We feel that a more effective screening program should be developed along with common sense advice to give school officials who measure high radon levels in their classrooms before it would be appropriate to recommend any kind of statewide action.

FOOTNOTES:

1. 4.27% * 0.95[low/medium] + 14% * 0.045[high] = 4.71%.
2. 0.045 * 0.6[high] + 0.058 * 0.401[medium] + 0.897 * 0.454[low]= 0.458.
3. 30 (average number of students in one classroom) * 2 (average number of classrooms with elevated radon levels per school) * 252 (expected number of schools exceeding 4 pCi/l) * [2/1000] (life time risk estimate of lung cancer in residence by EPA, 1993) * [1/4] (adjusted for aggregated population life time risk of lung cancer in schools) = 7.4 (students)

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TABLES

Table 1. Average School Radon Measurement and T-test Results

Radon Pot.	*N*	*Mean*	*SD*	*GM*	*Log(GM)*	*GSD*	*Log(GSD)*
All Data	367	0.610	0.530	0.460	-0.77	2.07	0.730
Low	254	0.595	0.522	0.454	-0.79	2.06	0.723
Medium	63	0.522	0.492	0.401	-0.913	2.03	0.706
High	50	0.775	0.627	0.600	-0.512	2.05	0.716
T-test	P						
Low-High	0.0067						
Low-Med	0.1122						
Med-High	0.0018						

Table 2. Statistics of Radon Measurement in Elementary School Classrooms

Radon Pot.	*Max*	*Mean*	*SD*	*GM*	*Log(GM)*	*GSD*	*Log(GSD)*
All Data	12.8	0.559	0.695	0.332	-1.103	2.960	1.085
Low	12.3	0.531	0.644	0.321	-1.136	2.916	1.070
Medium	3.7	0.442	0.473	0.259	-1.350	3.030	1.108
High	12.8	0.848	1.020	0.539	-0.618	2.643	0.972
Low-Med	12.3	0.512	0.612	0.307	-1.182	2.951	1.082

N=sample number
SD=standard deviation
GM=geometric mean
GSD=geometric standard deviation

Table 3. Probability of Radon Levels in Elementary School Classrooms

Radon Pot.	*P(>2)*	*P(>4)*	*P(>6)*
All Data	0.049	0.011	0.004
High	0.089	0.020	0.007
Low-Med	0.046	0.009	0.003

Table 4. Comparison of Radon Levels between Residences and Classrooms

	GM (pCi/L)	*GSD*	*Percentage of Exceeding 4 pCi/L*
Residence	0.85	1.91	0.84
Classroom	0.33	2.96	1.1

FIGURES

Figures can be found at http://www.cal-iaq.org/radon_figures.htm

Figure 1. Location of elementary schools selected to participate in Radon survey.
Figure 2. Elementary Schools with Measured Radon Levels of 4 pCi/L or Greater.
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